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Thrust-related accretion of an Archaean greenstone belt in the Midlands of Zimbabwe

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Abstract

Detailed structural data from the Midlands greenstone belt show that, in contrast to pre-existing models, the evolution of the greenstone belt involved an early episode of thin-skinned thrusting affecting separate lithological domains. These display different sedimentary and structural-metamorphic histories prior to their juxtaposition across steep, west-directed thrust zones. The domains include 3.5 Ga old gneiss, 2.67–2.88 Ga, mafic–felsic volcanic units and early-syn-tectonic, clastic sedimentary sequences. Concomitant with thrusting along domain boundaries, upright folding and 'minor' shear accommodated strain within domains.

The early thin-skinned, and later, steeper, thrusting events can be interpreted as progressive stages in an accretionary and crustal thickening sequence, possibly associated with under-plating or low-angle subduction. The clastic sedimentary sequences contain intraformational clasts and show coarsening upward cycles below major early thrust horizons, and may have formed on alluvial fans developing in front of west-moving nappes. Strike-slip motion on the main shear zones in the Midlands greenstone belt only occurred late in the tectonic history and there is no evidence that this resulted in large displacements. A shift of σ_1, from E–W to N–S during the late stages of Archaean deformation of the greenstone belt can be attributed to extensional collapse following E–W shortening and crustal thickening of the Zimbabwe craton.

Keywords: Accretion; Greenstone belt; Lithological domains

1. Introduction

Archaean cratons around the world are characterised by granite–greenstone terrains containing variably deformed and metamorphosed volcano–sedimentary assemblages, remnants of older quartzo–feldspathic gneiss and intrusive late granitoids. To date, no tectonic model has been agreed upon that can serve as a unique mechanism for formation of Archaean cratons. Discussions revolve around the question of whether cratonisation involved 'modern' accretionary processes related to plate tectonics in which greenstone stratigraphies comprise complexly deformed rock assemblages juxtaposed during collisional orogenesis (cf. de Wit, 1982, 1998; Kusky and Polat, 1999), or whether growth resulted from vertical accretion and deformation in fixed positions (e.g. above mantle plumes; Nisbet et al., 1981).

The Zimbabwe craton in southern Africa (Fig. 1, inset) has an areal extent of 177,000 km^2 and is characterised by a greenstone:granite (*sensu lato*) ratio of about 1:5 (Blenkinsop et al., 1993, 1997). It has a long history of crustal growth that started in the early Archaean (~3.5 Ga), and became a stable crustal segment at around 2.6 Ga with the emplacement of late- to post-tectonic monzogranites (Jelsma et al., 1996), shortly followed by the Great Dyke (2.58 Ga: Mukasa et al., 1998). The majority of rocks (c. 90%) formed between 2.9 and 2.6 Ga ago, and include volcanic and sedimentary units of the Belingwean (2.9 Ga), Lower Bulawayan (2.8 Ga), Upper Bulawayan and Shamvaian (2.7–2.6 Ga) greenstones, and voluminous granite plutons that have been assigned to the Chingezi (2.9 Ga), Sesombi and Wedza (2.7–2.6 Ga) suites (Wilson et al., 1995).

Evolutionary models for the Zimbabwe craton (e.g. Wilson, 1979; Wilson et al., 1995) are generally linked to a specific interpretation of the stratigraphy of the greenstone sequences, which assumes cyclic greenstone–granite magmatism and deposition of greenstones in intracontinental rift settings forming distinctive, non-repetitive, autochtonous successions (e.g. Nisbet et al., 1981; Bickle et al., 1994; Wilson et al., 1995). Craton-wide stratigraphic correlations are based on the ubiquitous Upper Bulawayan rocks and correlations are linked to the Ngezi Group in the

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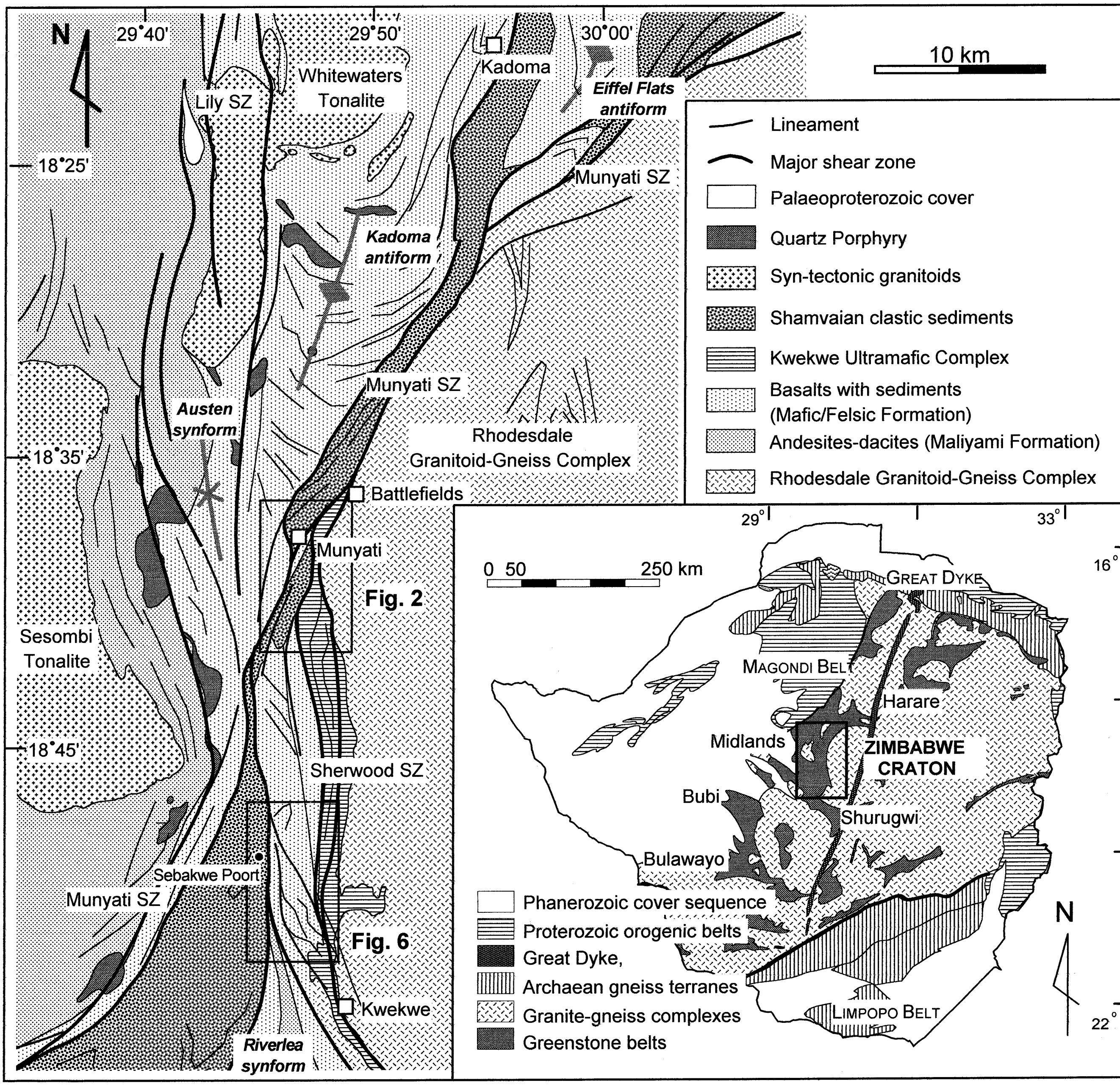

Fig. 1. Location map showing the study area and the major structural and lithological features in the Midlands Greenstone Belt (adapted from Campbell and Pitfield, 1994).

Belingwe greenstone belt where the type section for the Upper Bulawayan stratigraphy has been defined (Wilson, 1979). Subsequent deformation is usually related to the emplacement of granites (Jelsma et al., 1993), or to far field stresses associated with the Limpopo orogeny (Treloar and Blenkinsop, 1995).

Alternative models for the late Archaean evolution of the Zimbabwe craton have been proposed by Dirks and Jelsma (1998) and Kusky (1998). Dirks and Jelsma (1998) and Jelsma and Dirks (2000a) recognised that the stratigraphy of most greenstone belts is cut by a large number of shear zones that typically parallel compositional layering or cut layering at low angles. They suggested that the layer-parallel shear zones are early thrusts that profoundly affected stratigraphy. Good examples of inverted stratigraphies and layer-parallel shears associated with low-angle stratigraphic truncations have been found in many greenstone belts in Zimbabwe. These include the Gwanda (Fuchter, 1990), Shurugwi (Stowe, 1984), Bulawayo (Garson, 1995), Belingwe (Kusky and Winsky, 1995), Dindi (Barton et al., 1991), Midlands (Dirks and van der Merwe, 1997) and Harare–Shamva (Jelsma and Dirks, 2000a) greenstone belts. Dirks and Jelsma (1998) suggested that the layer-parallel shear zones accommodated westward stacking of thrust sheets, which included mafic and ultramafic oceanic sequences, juvenile volcanic arcs, and older crustal fragments. According to Kusky (1998) the Zimbabwe greenstone belts consist of magmatic arc and back-arc volcanics, and passive-margin sediments that collided with a large, ancient, stable, crustal fragment (Tokwe terrane).

In this paper we present detailed structural data from the Midlands greenstone belt (Fig. 1, inset), which bears on the above discussion. The deformation history of this greenstone belt has been commonly linked to diapirism followed by repeated stages of strike-slip movement on conjugate sets of large-scale shear zones (Stowe, 1980; Campbell and Pitfield, 1994). We will show that this interpretation is incomplete and that the evolution of the greenstone belt involved lateral accretion of separate tectono–stratigraphic terranes. These terranes are each characterised by distinct sedimentary and structural histories prior to their juxtaposition across west-directed thrust zones.

2. Regional geological setting

The Midlands greenstone belt (MGB) in the central Zimbabwe craton represents the largest greenstone outcrop (Fig. 1), with the highest concentration of gold mines in Zimbabwe (e.g. Foster et al., 1986; Campbell and Pitfield, 1994). The belt has a slightly arcuate, roughly N–S trend and consists of interlayered sequences of clastic metasediment, and felsic and mafic metavolcanic rocks, which envelop the ovoid Rhodesdale Granitoid–Gneiss Complex (Rhodesdale GGC) that occurs to the east. The western margin of the belt is covered by younger sediments belonging to the Palaeoproterozoic Magondi belt, the Palaeozoic to Mesozoic Karoo Supergroup and Cenozoic Kalahari sands.

To the NE, the MGB can be traced across the Great Dyke into the Harare greenstone belt; to the SW it can be traced around the Shangani batholith into the Bubi and Bulawayo greenstone belts, and to the SE, across a major E–W-trending lineament, it forms a continuum with the Gweru and Shurugwi greenstone belts (Fig. 1).

Based on regional stratigraphic models that assume continuity of regional unconformities and lithological associations (Wilson, 1979; Wilson et al., 1995), the greenstones of the MGB have largely been assigned to the late Archaean, Upper Bulawayan and Shamvaian (ca. 2.7–2.6 Ga) Groups (Wilson, 1979). The greenstones along the eastern side of the belt consist of tholeiitic basalt and gabbro of the What Cheer or Mafic Formations (Robertson, 1976; Wilson, 1979), variably dated at 2683 ± 8 Ma (Pb–Pb, single zircon, SHRIMP; Wilson et al., 1995) or 2880 ± 8 Ma (U–Pb, single zircon, TIMS; Horstwood, 1998). These are overlain by a bimodal mafic–felsic unit with intercalated sediment that is commonly referred to as the Felsic Formation (Bliss, 1970). Towards the centre of the greenstone belt occurs a narrow (1–10 km) NNE-trending fault-bounded unit of clastic sediment interbedded with felsic volcanic rocks that has been assigned to the Shamvaian Group (Bliss, 1970; Harrison, 1970; Wilson, 1979). Further west, across a major shear zone (the Lily shear: Campbell and Pitfield, 1994), the nature of the Upper Bulawayan greenstones changes to a thick, monotonous sequence of calcalkaline andesite and dacite of the Maliyami Formation assumed to be stratigraphically above the Felsic Formation (Wilson, 1979; Wilson et al., 1995) and dated at 2702 ± 6 Ma (Pb–Pb, single zircon, SHRIMP; Wilson et al., 1995). The boundary of both sequences is accentuated by elongated bodies of quartz-feldspar porphyry that were emplaced at 2677 ± 6 Ma (U–Pb, single zircon, TIMS; Horstwood, 1998). The contact between the greenstones and the Rhodesdale GGC is characterised by an up to 5-km-wide ultramafic unit, which extends from Kwekwe in the south to Battlefields in the North and belongs to the Kwekwe Ultramafic Complex (Harrison, 1970). It consists of carbonated and silicified serpentinite, talc schist and chlorite schist, and has been variably interpreted as an older Sebakwian unit (e.g. Macgregor, 1951), or as a younger intrusive unit (Harrison, 1970). The greenstones were intruded by several large, syn- or inter-tectonic plutons of granodioritic to tonalitic composition assigned to the Sesombi suite (Wilson, 1979) and dated at c. 2670 Ma (Pb–Pb, single zircon, Kober; Dougherty-Page, 1994; U–Pb, single zircon, TIMS; Horstwood, 1998).

The Rhodesdale GGC is separated from the MGB by a strongly sheared contact. The complex is a tonalitic to granodioritic, composite granite–gneiss terrane, containing numerous tightly folded greenstone fragments in migmatitic gneiss, intruded by younger, variably foliated granodioritic to granitic bodies (Harrison, 1970). The older gneiss units have been dated at 3456 ± 6 Ma (U–Pb, single zircon, TIMS; Horstwood, 1998). A sliver of gneiss material, interlayered with the Mafic Formation along the Sebakwe River, but correlated with the Rhodesdale GGC has been dated at 3565 ± 21 Ma (U–Pb, single zircon, TIMS; Horstwood, 1998).

Although simple stratigraphic models have been proposed for the greenstones of the MGB, and contacts between units are commonly referred to as unconformable (e.g. Macgregor, 1951; Bliss, 1970; Harrison, 1970; Robertson, 1976; Wilson, 1979; Wilson et al., 1995), many contacts between major stratigraphic units are strongly sheared (e.g. Catchpole, 1987; Campbell and Pitfield, 1994; Buchholz et al., 1998; Manyanhaire, 1998). Further stratigraphic complications are presented by the monotonous compositional nature of most greenstone lithologies, the lack of marker horizons, and the general discontinuous nature of individual units along strike.

3. The existing structural framework

Consistent with its low metamorphic grade, the structural history of the belt is characterised by a high degree of strain

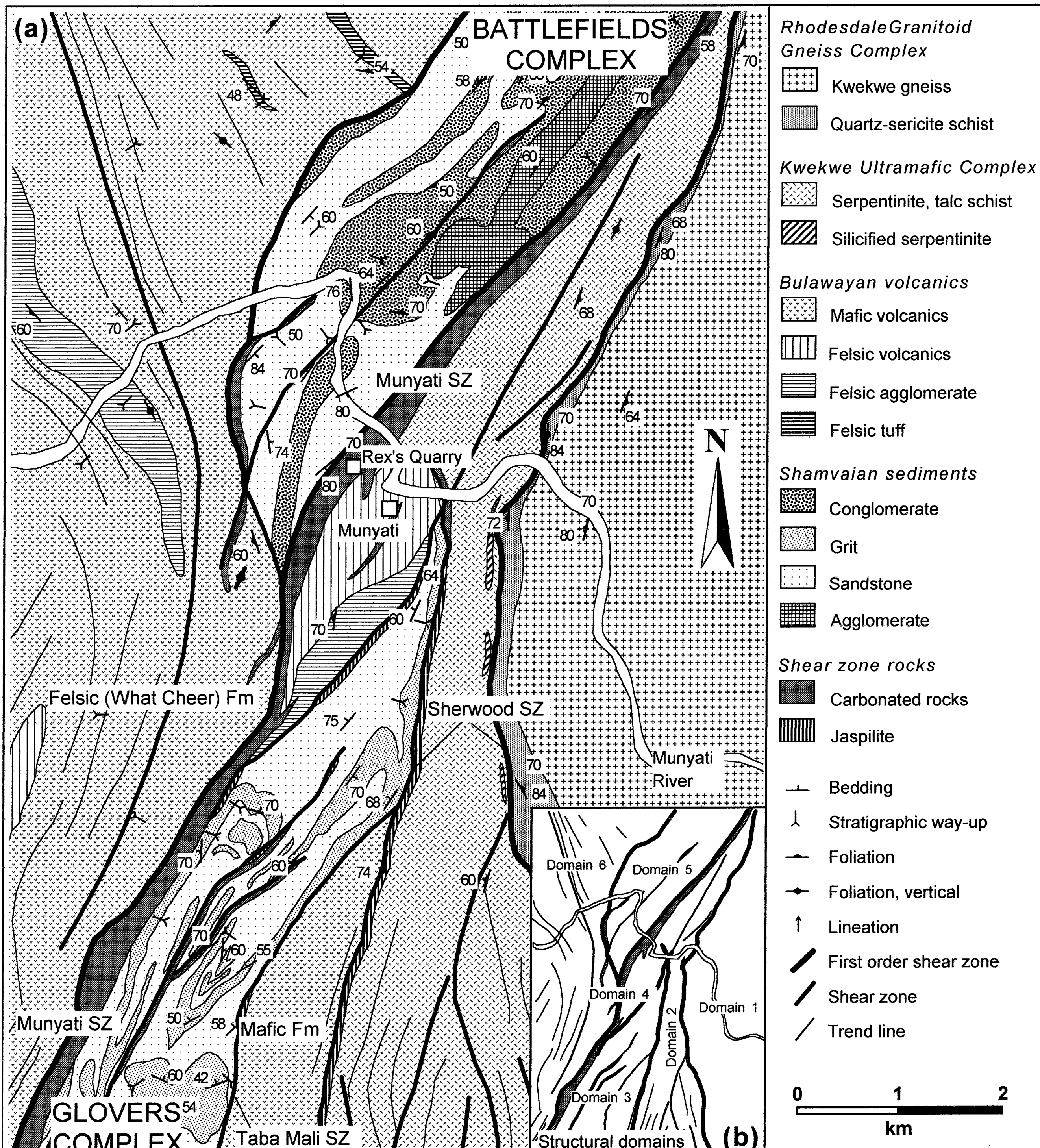

Fig. 2. (a) Geology of the Munyati area, with from east to west the Rhodesdale GGC, the Sherwood shear zone, the Kwekwe ultramafic complex, the Mafic Formation (south), the Glovers sedimentary complex (south), the Munyati shear zone, the Battlefields sedimentary complex (north) and the Felsic (What Cheer) Formation. (b) Outline map showing structural domains described in the text.

partitioning, in which first order shears including the Munyati, Sherwood, Lily and Taba–Mali shear zones (Fig. 2) separate lower strain domains characterised by large-scale upright folds (Campbell and Pitfield, 1994). Such folds and an associated axial planar cleavage have been linked to diapiric emplacement, doming or tectonic extrusion of the surrounding batholiths including the Rhodesdale GGC (e.g. Wilson, 1990; Campbell and Pitfield, 1994; Herrington, 1995; Treloar and Blenkinsop, 1995). In these interpretations, earlier complex fold structures have been attributed to syn-sedimentary slumping. The principal far field stress causing regional folding is either perceived as E–W compressional (e.g. Buchholz, 1995) or as NNW–SSE compressional (Bliss, 1970; Coward, 1976; Herrington, 1995).

The large-scale shear zones, and a complex network of secondary and tertiary shears, have been explained with a multistage strike-slip history (e.g. Stowe, 1980; Catchpole, 1987; Wilson, 1990) assumed to have taken place during the final stages and after stabilisation of the Zimbabwe craton. Although complicated kinematic histories have been proposed for the shears (e.g. Stowe, 1980; Campbell and Pitfield, 1994), such histories are generally based on the interpretation of remotely sensed data and are devoid of rigorous structural field observations.

The clastic Shamvaian sediments in the MGB occur in narrow domains bounded by major shear zones that preserve evidence of late-stage strike slip motion. As a result, the sediments have been linked to syn-tectonic deposition in a transtensional environment (Harrison, 1970; Wilson, 1979; Stowe, 1980; Campbell and Pitfield, 1994). A genetic link between the sediment fill and the surrounding greenstones is therefore expected (Campbell and Pitfield, 1994), even though it has been noted that the composition of the clasts is different from the dominant lithologies in adjacent greenstones (Macgregor, 1951; Harrison, 1970).

Existing structural models for the MGB tend to focus exclusively on the later, more obvious deformation features. As a result complicated geometries and lithological relationships, including repeated younging reversals in otherwise 'simply– layered greenstone sequences (e.g. Campbell and Pitfield, 1994; Fig. 3), remain unexplained. Early isoclinal folding and thrusting predating the formation of the large-scale upright folds, have been noted in sections of the MGB (e.g. Nutt, 1984; Dirks and van der Merwe, 1997; Manyanhaire, 1998). Considering the tectonic significance attributed to such structures in greenstone belts around the world, the true nature of these early structures needs to be closely investigated.

Two areas have been selected for detailed structural analyses in the Kadoma–Kwekwe section of the MGB: Munyati and Sebakwe Poort (Fig. 1). Both areas consist of fault-bounded geological domains with unique lithological (Table 1) and structural–metamorphic associations (Table 2; Macgregor, 1951; Bliss, 1970; Harrison, 1970; Robertson, 1976; Campbell and Pitfield, 1994; Buchholz, 1995). For each area, a detailed structural history has been compiled that can be used for comparative purposes across the greenstone belt, and the validity of existing stratigraphic and tectonic models has been assessed.

4. The Munyati area

In the area around Munyati town (Fig. 2) the gneissic and greenstone lithologies have been divided into six structural–lithological domains. From east to west these are: Domain 1, the western margin of the Rhodesdale GGC including the Sherwood shear zone; Domain 2, the Kwekwe Ultramafic Complex and its sheared western margin; Domain 3, the Glovers Sedimentary Complex; Domain 4, the Munyati shear zone; Domain 5, the Battlefields Sedimentary Complex; Domain 6, volcanics of the Felsic Formation (Fig. 2). This scheme could be extended to include a sliver of Mafic Formation that occurs between the Kwekwe Ultramafic Complex and the Glovers Sedimentary Complex to the south of Munyati town, but this unit has been described for the Sebakwe Poort area below.

4.1. Domain 1, western margin of the Rhodesdale GGC including the Sherwood shear zone

East of Munyati town the quartzo–feldspathic gneiss at the western margin of the Rhodesdale GGC dips steeply W (Fig. 3a). Mafic dykes truncate S_1 and contain an internal gneissic foliation, S_2, with a steeply plunging hornblende lineation. Subvertical, NNE-trending garnet–hornblende-bearing shear zones (S_3) with a steep hornblende lineation, L_3 (Fig. 3b), truncate S_1 and S_2. The shear zones accommodated E-up, dextral movement and parallel a mylonitic quartz–sericite schist developed within an intrusive granite sheet that occurs along the western contact of the Rhodesdale GGC. The mylonite marks an eastern branch of the Sherwood shear zone and the western boundary of the Rhodesdale GGC. It has a northerly strike (Fig. 3c), a steeply NNE-plunging mineral lineation, L_3 (Fig. 3c), and contains S–C and C–C' fabrics that indicate E-up movement. The mylonite is locally crenulated (D_{3b}) and truncated by slickensided brittle–ductile fractures (D_4) for which no systematic data was obtained.

4.2. Domain 2, the Kwekwe Ultramafic Complex and its sheared western margin

The Kwekwe Ultramafic Complex (Fig. 2) near Munyati town contains remnants of cumulate-textured serpentinitic dunite enveloped by foliated talc–tremolite–carbonate schist, best developed near major shear zones within, and along, the margins of the complex. The contacts of the complex are extensively silicified and carbonated and consist of two branches of the Sherwood shear zone to the E and SW, and the Munyati shear zone to the NW. The SW contact is marked by a jaspilitic chert horizon that truncates bedding in adjacent domains (Fig. 2). Locally, this chert is brecciated with fragments embedded in a matrix of gossanous material cut by quartz veins. Towards the north the chert passes into strongly sheared, carbonated talc–tremolite schist. These characteristics indicate that the jaspilite horizon represents a silicified shear zone.

In talc–tremolite schist, an early S_1 foliation is largely replaced by an S_2, crenulation cleavage. In serpentinite S_2

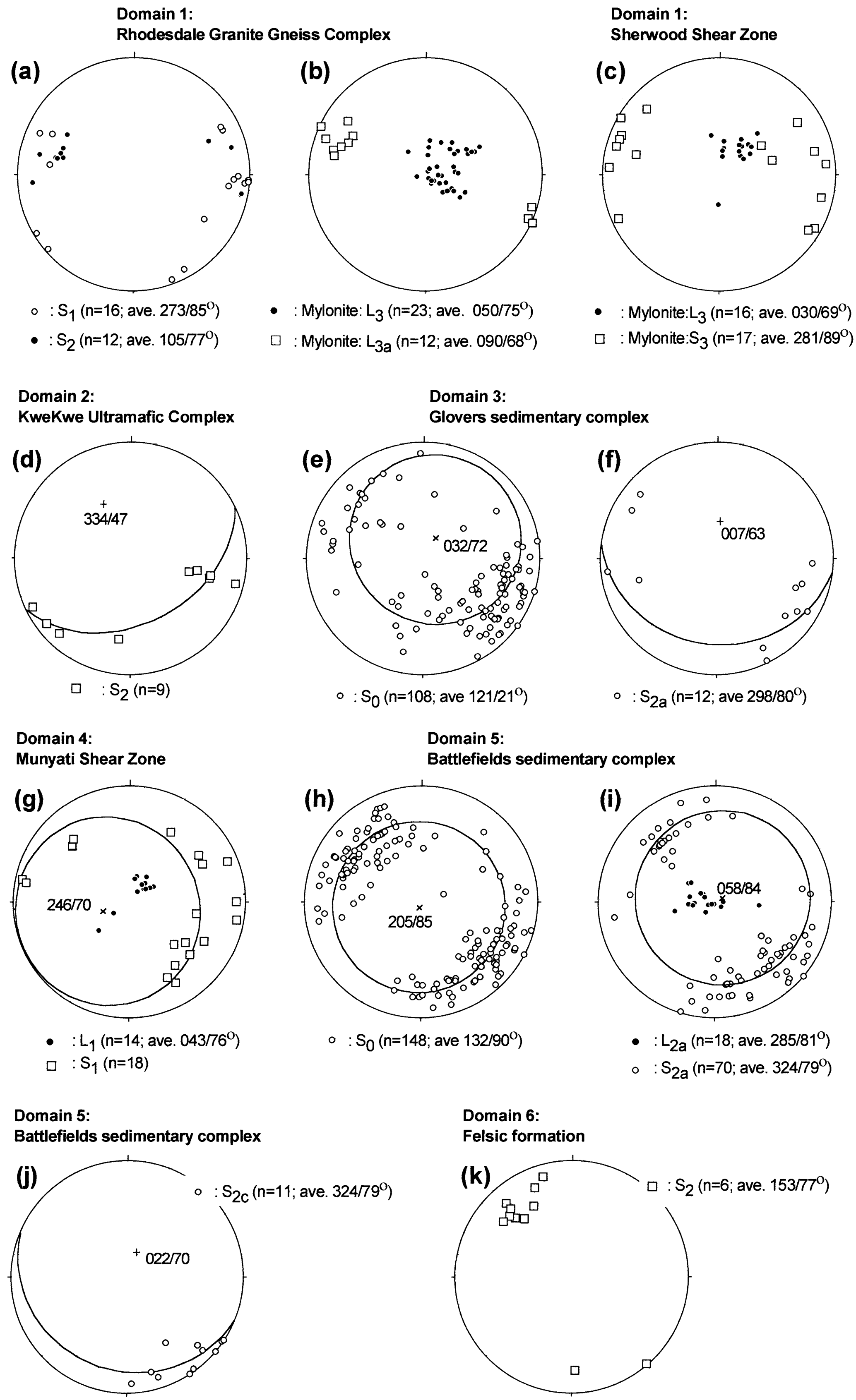

Fig. 3. Lower hemisphere equal area stereographic projections for poles to foliation and for linear fabrics in the Munyati area (see text for discussion).

Table 1
Summary of the main lithological associations and their formation names in the tectonic domains in the Sebakwe Poort and Munyati areas

Area	Domain	Formation/group	Lithological description
Munyati	Domain 1	Rhodesdale Granitoid–Gneiss Complex	Strongly foliated quartzofeldspathic gneiss intruded by variably deformed felsic and mafic bodies/dykes.
	Domain 2	Kwe Kwe Ultramafic Complex	Cumulate-textured serpentinitic dunite enveloped by foliated talc–tremolite–carbonate schist. Locally contains chert horizons that mark shear zones.
	Domain 3	Basal Grit Formation, Shamvaian Group (Robertson, 1976)	Coarse-grained pebbly sandstone with intercalated siltstone, phyllite and rare conglomerate beds. The pebbly sandstone contains sub-rounded to sub-angular pebbles that consist of (in decreasing order of abundance) white vein quartz, microgranite and banded or massive chert. Cross-bedding, graded bedding and parallel laminations are well preserved. Haematitic sandstone and chert horizons are restricted to shear zones.
	Domain 4	Munyati shear zone, Kwe Kwe Ultramafic Complex	Strongly carbonated ultramafic rocks forming fuchsite- and magnesite-bearing marbles as well as tectonic melanges of sheared and carbonated ultramafic, mafic and felsic volcanic blocks set in a carbonaceous matrix
	Domain 5	Volcaniclastic Formation, Shamvaiian Group (Robertson, 1976)	Conglomerate and pebbly sandstone containing abundant felsic volcanic fragments. Shale and volcano–sedimentary horizons occur in lesser amounts. Conglomerate in the Munyati area, contains sub-rounded to rounded pebbles of (in decreasing order of abundance) jaspilite (laminated and folded), sand-, silt- and mudstone, rhyolite or rhyodacite, grey chert, dacite and granite. Greenstone clasts are absent.
	Domain 6	Felsic Formation or Bimodal volcanic suite, Upper Bulawayan Group (Harrison, 1970; Wilson, 1979)	Massive and vesicular, pillowed basalts with intercalations of felsic agglomerate, tuff, and minor chert or jaspilite. Basalts are strongly carbonated. Massive varieties are fine-grained, but doleritic and gabbroic units occur. The felsic agglomerate and tuff contain clast-supported angular to subrounded dacitic to rhyolitic blocks, bombs and lapilli in a tuffaceous matrix with sand-sized quartz crystal fragments. The tuff locally shows graded bedding and ripple laminations.
Sebakwe Poort	Domain 1	Kwe Kwe Ultramafic Complex	As above.
	Domain 2	Mafic Formation, Upper Bulawayan Group (Wilson, 1979)	Pillowed and massive basalts interlayered with doleritic to gabbroic units and thin jaspilite horizons, ferrugenous shales, quartz arenites or grits, felsic volcanics and ultramafic lithologies that are locally intensely carbonated and silicified (see also Fig. 8).
	Domain 3	Taba–Mali shear zone, Shamvaian Group	Contorted and disrupted shale and silt horizons that are carbonated and ferrugenised.
	Domain 4	Basal Grit Fm, Lower Greywacke Fm., Shamvaian Group (Harrison, 1970)	Conglomerate and poorly sorted sandstone and shale overlain by conglomerate. Sedimentary structures are well preserved. Clasts in conglomerate consist mostly of jaspelite and chert fragments with minor vein quartz, whilst mafic greenstone fragments are absent.

Table 2
Summary of the deformation events affecting the different tectonic domains in the Sebakwe Poort and Munyati areas. 1: Mafic Formation, Dacite, SHRIMP, zircon; Wilson et al. (1995); 2: Mafic Formation, Dacite, single zircon, TIMS; Horstwood (1998); 3: Gneiss inlier in Mafic Formation, single zircon, TIMS; Horstwood (1998); 4: Gneiss, single zircon, TIMS; Horstwood (1998)

Deformation events	Sebakwe Poort				Munyati						
	Domain 1 Age (Ma): ?	Domain 2 Age (Ma): 2683 ± 8, 1 2880 ± 8, 2 3565 ± 21, 3	Domain 3 Age (Ma):	Domain 4 Age (Ma):	Domain 1 Age (Ma): 3456 ± 6, 4	Domain 2 Age (Ma): ?	Domain 3 Age (Ma): ?	Domain 4 Age (Ma): ?	Domain 5 Age (Ma): ?	Domain 6 Age (Ma): ?	Region. deform. scheme
1: Development of gneissic layering					D_1						*DIa*
2: Intrusion of mafic dykes					Yes						
3: Development of gneissic layering in mafic dykes	D_0 ?				D_2 L_2 = vert.						*D1b*
4: Emplacement of granites					Yes						
5: Formation of intraformational clasts and slumps in sedimentary sequences				Yes, No basalt clasts			Yes, No basalt clasts		Yes, No basalt clasts		
6: Isoclinal folding and reversals in younging direction associated with early layer-parallel shear and thrust stacking. Thrusting may occur without younging reversals		D_1 L_1 = Horiz $S_1//S_0$	D_1 L_1 = ?	D_1 L_1 = 110/00 Top to W $S_1//S_0$			D_1 L_1 = ? $S_1//S_0$		D_1 L_1 = ? $S_1//S_0$	D_1 L_1 = ? $S_1//S_0$	*DII*
7: Intrusion of the Kwe Kwe ultramafic complex	Yes	Yes				Yes					
8: Upright to reclined folding and development of N- to NE-trending axial planar foliation and a steep NE-plunging lineation that parallels a steep NE-plunging fold axis	D_1 L_1 = Horiz	D_2 $L_2//B_2$ = 019/78		D_2		D_1 L_1 = ?	D_{2a} $B_2//L_2$ = 032/72		D_{2a} $B_2//L_{2a}$ = 285/81	D_2 B_2 = steep	*DIIIa*
9: Development of shear zones with a steep NE-plunging lineation and E-up, dextral sense of movement. Minor shears occur in limbs of upright folds. Major shears form domain boundaries	D_2 $L_2//B_2$ = 016/61 E-up, dex. σ_1 = ENE	D_2	D_2 $L_2//B_2$ = 320/75 E-up, dex.	D_2 B_2 = 042/10	D_{3a} L_3 = 030/69 E-up, dex.	D_2 B_2 = 335/50	D_{2b}	D_1 L_1 = 043/76	D_{2b} L_2 = 075/80 E-up, dex.		*DIIIb*
10: Crenulation of the shear zone fabrics					D_{3b}		D_{2c}		D_{2c}		*DIIIc*
11: Open recumbent folding, and development of a sub-horizontal fracture cleavage				D_3							*DIIId*
12: Emplacement of felsic porphyry dykes									Yes		
13: Development of slickensided fault structures with dextral shear on the Sherwood shear zone	D_3 σ_1 = 240/07 σ_3 = 331/02	D_3 σ_1 = 240/07 σ_3 = 331/02			Probably present but not directly observed						*DIV*
14: Emplacement of felsic porphyry dykes and mafic dykes	Yes	Yes									
15: Development of slickensided fault structures with sinistral shear on the Munyati shear zone	D_4 σ_1 = 013/06 σ_3 = 145/81	D_4 σ_1 = 013/06 σ_3 = 145/81			D_4	D_3	D_3	D_2 σ_1 = 352/09 σ_3 = 087/14	D_3 σ_1 = 355/10 σ_3 = 262/03	D_3	*DV*

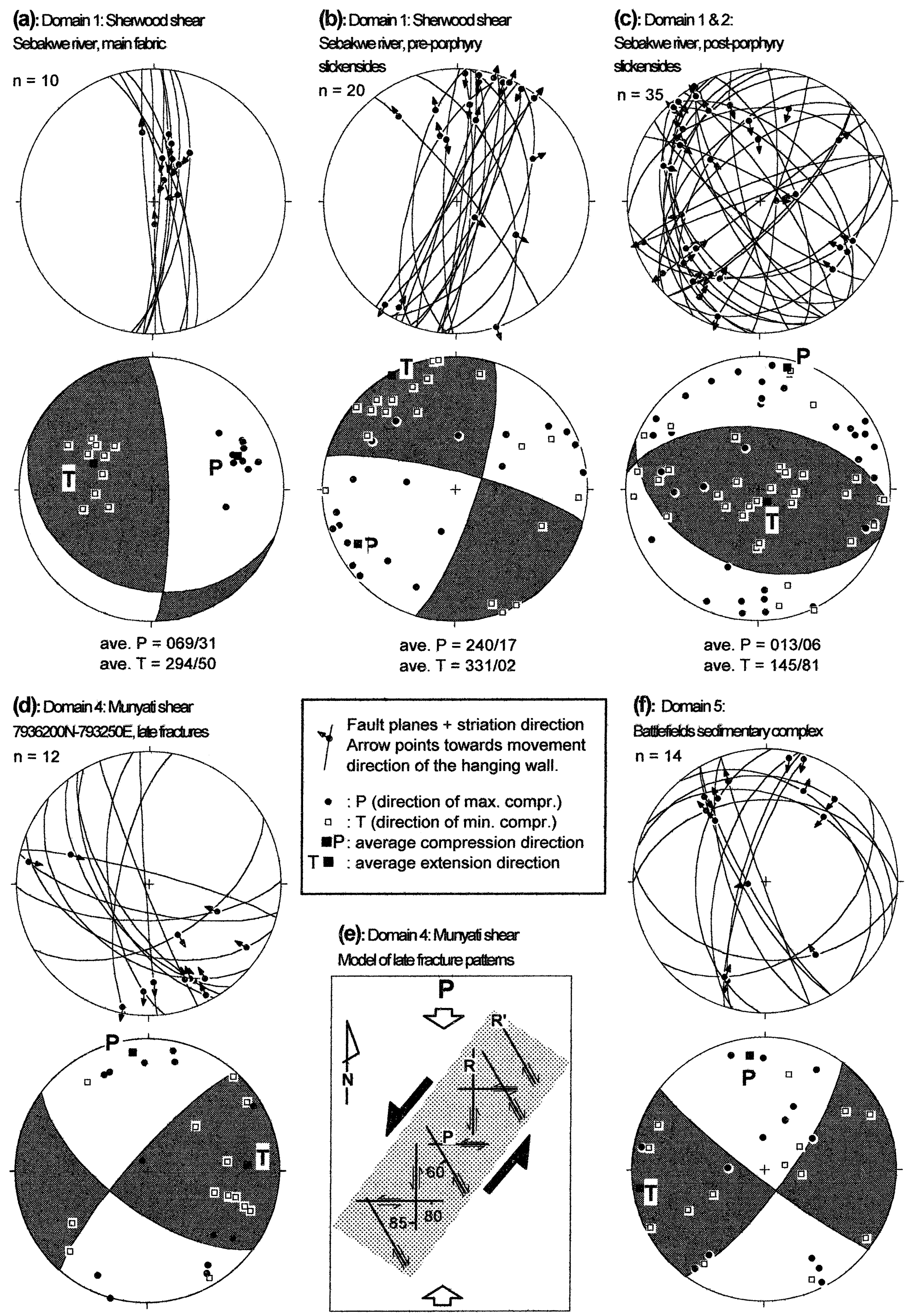

Fig. 4. Fault orientations, striations and kinematic analysis using *P–T* dihedra.

is preserved as a disjunctive cleavage defined by anastomosing trails of iron oxide. S_2 is variable in orientation, and poles to S_2 display a great circle distribution around a c-pole direction that plunges north at moderate angles (Fig. 3d). S_2 is overprinted by unoriented tremolite growth, extensive carbonatisation and brittle–ductile fractures that are best developed near the Munyati shear zone.

4.3. Domain 3, the Glovers Sedimentary Complex

The deformation history of the Shamvaian Group clastic sediments of the Glovers Sedimentary Complex is similar to that described in detail for Domain 5 although the sedimentary fill in this domain is different (Table 1). In brief, deformation involved an early stage of isoclinal folding, with associated layer-parallel shear zones and a slaty cleavage

(S_1) developed in shale horizons. D_1 features were overprinted by D_2, upright folds that dispersed S_0 and S_1 around NE plunging π-poles (Fig. 3e and f). A stretching lineation (L_2) defined by elongated pebbles parallels this axis. D_2 shear zones developed along the limbs of many D_2 folds, and break up the stratigraphy in numerous shear-bounded blocks. These shears are characterised by ferrugenous chert horizons and are commonly reactivated as slickensided, strike-slip zones (D_3) associated with carbonatisation.

4.4. Domain 4, the Munyati shear zone

The Munyati shear zone (Fig. 2) is a 200–400-m-wide, NE-trending shear zone that separates the Kwekwe Ultramafic Complex from the Battlefields Sedimentary Complex to the north, and volcanic rocks from the Glovers Sedimentary Complex to the south (Table 1). The dominant S_1 foliation within the Munyati shear zone is steep with a NE trend. S_1 is associated with a steeply NE-plunging, L_1 mineral lineation defined by mica trails, carbonate rodding or tremolite grains (Fig. 3g) and locally folded around near vertical folds. As a result of post D_1 carbonatisation and recrystallisation, no unambiguous shear sense could be obtained.

The D_1 shear fabric in the Munyati shear zone is truncated by a complex network of D_2, slickensided, fracture planes with sub-horizontal lineations and associated quartz–carbonate veins. At Rex's Quarry (7936200N–793250E), the D_2 fractures define Riedel, anti-Riedel and P-shears within a large-scale sinistral system (Fig. 4d and e). Kinematic analysis of the fault-slip data suggests that fault motion occurred in response to N–S compression and E–W extension (Fig. 4d; Lisle, 1987; Marrett and Allmendinger, 1990).

4.5. Domain 5, the Battlefields Sedimentary Complex

The Battlefields Sedimentary Complex consists of Shamvaian Group clastic rocks (Table 1), and is enveloped by strongly silicified and carbonated shear zones that truncate primary layering within the complex (Fig. 2). The earliest deformation features in the sediments relate to rounded pebbles of contorted jaspilite beds indicative of deformation in the sediment source area. The presence of large numbers of intraformational sandstone and shale clasts (Table 1) suggests a possible coincidence of sedimentation with deformation and rejuvenation of the basin margin. Slump structures are common in shale beds interbedded with sandstone and conglomerate.

The earliest ductile deformation, D_1, relates to 50–100-m-scale isoclinal folds and reversals in younging direction that occur independently of reversals in angular relationships between primary layering (S_0) and the dominant cleavage in the area (S_2). D_1 is associated with a layer-parallel slaty cleavage, S_1, best developed within shale horizons interbedded with sandstone. Layer-parallel, D_1 shear zones also occur and display ramp–flat geometries and duplex arrays suggesting thin-skinned thrusting during D_1 (e.g. 7937893N–792944E; Fig. 5).

D_1 structures were refolded by upright, inclined D_{2a} folds with near-vertical fold axes and a penetrative, generally steep, NE-trending axial planar cleavage, S_{2a} (Fig. 3i). S_{2a} contains a steeply plunging, L_{2a} mineral lineation defined by aligned mica grains (Fig. 3i) that parallel elongated pebbles. Many of the D_{2a} folds have sheared limbs and are truncated by a complex, anastomosing network of younger shear zones (D_{2b}) that break up the stratigraphy in numerous, 10-m-scale fault-bounded blocks (Fig. 5). The larger of these shear zones occur along the limbs of 500-m-scale D_{2a} folds. L_{2b} lineations on the shears are preserved as fine striations and plunge steeply to the east (Fig. 5), parallel to L_{2a}. S–C fabrics and foliation bending indicate an E-up, dextral sense of movement. The shear zone fabric (S_{2b}) is locally overprinted by an ENE-trending crenulation cleavage that may have formed as an accommodation structure during the later stages of D_2 (D_{2c}; Fig. 3j; Table 2). In many places, D_{2b} shears merge with D_1 shears that were folded during D_{2a}, suggesting that the entire sequence of structures is progressive. Locally, N-trending, near-vertical feldspar porphyry dykes truncate or parallel the shears. The dykes are weakly foliated and, therefore, late-syn-kinematic.

Many D_{2b} shear zones are reactivated as D_3 strike-slip faults with associated laminated quartz veining and carbonatisation of the wall rock (Fig. 5). They are part of a network of D_3, slickensided faults that include shallowly NNE-dipping thrusts, and conjugate sets of NNE-trending sinistral and NW-trending dextral faults (Fig. 4f). Kinematic analysis of the fault-slip data suggests that fault motion occurred in response to N–S compression and E–W extension (Fig. 4f; Lisle, 1987; Marrett and Allmendinger, 1990).

4.6. Domain 6, volcanic rocks of the Felsic Formation

In the northern part of Domain 6 (Fig. 2), the regional SE trend of inter-layered, felsic–mafic volcanic rocks is abruptly truncated by the NE-trending, carbonated shear zone that forms the contact with the Battlefields Sedimentary Complex. To the south, the lithological layering rotates to the SW into parallelism with the Munyati shear zone (Fig. 2).

In this domain, D_1 is associated with 5-km-scale isoclinal folds, reversals of younging direction (Campbell and Pitfield, 1994) and a layer-parallel foliation best preserved in fine-grained tuff and silicified, graphitic shear horizons (see also Nutt, 1984; Manyanhaire, 1998). NE-trending, upright D_2 folds, including a regional anticlinorium referred to as the Kadoma anticline, refolded D_1 geometries. The upright folding is associated with a steeply dipping, NE-trending axial planar cleavage (S_2; Fig. 3k) that contains a steeply NE-plunging mineral lineation.

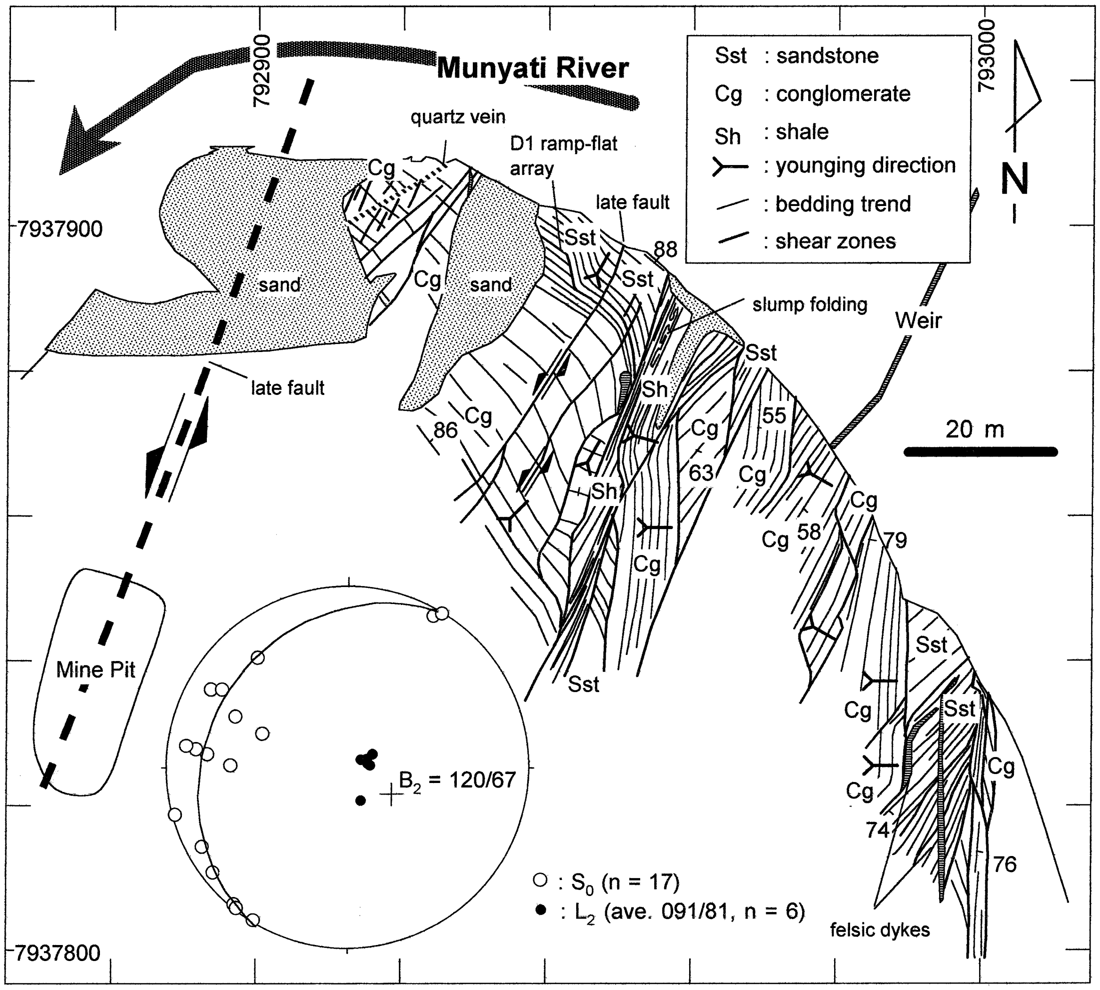

Fig. 5. Rock platform at the south bank of the Munyati river, 2.5 km NNW of Munyati town (7937880N–792950E), showing disruption of the stratigraphy, intrusion of late-kinematic felsic dykes and subsequent folding of the stacked package.

As in all other domains, S_2 is transected by slickensided strike-slip faults.

5. Sebakwe Poort area

In the Sebakwe Poort area NW of Kwekwe (Fig. 1), the gneiss and greenstone litholgies along the Sebakwe River (between Sebakwe Poort and the Rhodesdale GGC) have been divided into four structural–lithological domains, which are from east to west (Fig. 6): Domain 1, the Kwekwe Ultramafic Complex and its sheared western margin, the Sherwood shear zone; Domain 2, complexly interleaved greenstones of the Mafic Formation; Domain 3, the Taba–Mali shear zone positioned within Shamvaian shale and poorly sorted sandstone; Domain 4, folded clastic sediments assigned to the Shamvaian Group.

5.1. Domain 1, Kwekwe Ultramafic Complex including the Sherwood shear zone

The Kwekwe Ultramafic Complex (Fig. 6) consists of variably deformed serpentinite rocks. The eastern contact with mid-Archaean gneiss of the Rhodesdale GGC is intrusive (Harrison, 1970). The western contact with Domain 2 is the 200–300-m-wide Sherwood shear zone (Campbell and Pitfield, 1994) characterised by intensely foliated and variably lineated talc–tremolite schist. Intense alteration along the shear has locally resulted in massive carbonate horizons. A sliver of sheared and retrogressed granitic gneiss (now quartz–sericite–chlorite schist) of the Rhodesdale GGC has been incorporated in the Sherwood shear zone near the Sebakwe River (Fig. 6).

The Sherwood shear zone is characterised by a pervasive, near-vertical, NNE-trending composite S_1/S_2 foliation (Fig. 7a). In the south this foliation contains a subhorizontal tremolite–magnesite lineation, L_1, that is overgrown by a steeply plunging tremolite lineation, L_2 (Fig. 7b). L_2 parallels the axes of disharmonic folds that are best developed in ultramafic schist east of the Sherwood shear zone. Near the Sebakwe River, only L_2 lineations are preserved and S–C and C–C' fabrics in quartz–sericite–chlorite schist indicate E-up movement.

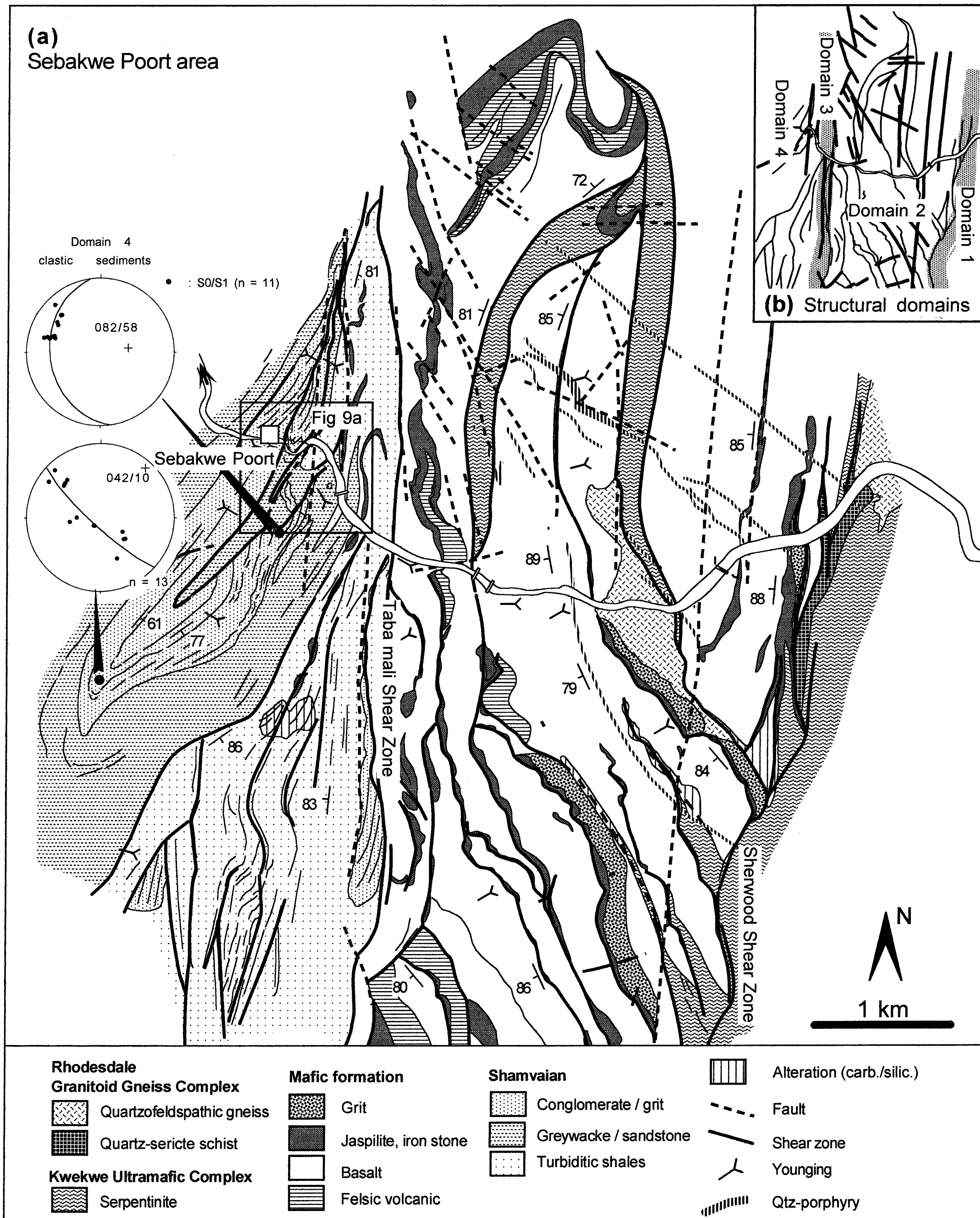

Fig. 6. (a) Geology of the Sebakwe River area, with from east to west the Rhodesdale GGC, the Sherwood shear zone, the Kwekwe Ultramafic Complex, the Mafic Formation including the Sebakwe River gneiss sliver and the Shamvaian sediments. (b) Outline map showing structural domains. See text for details.

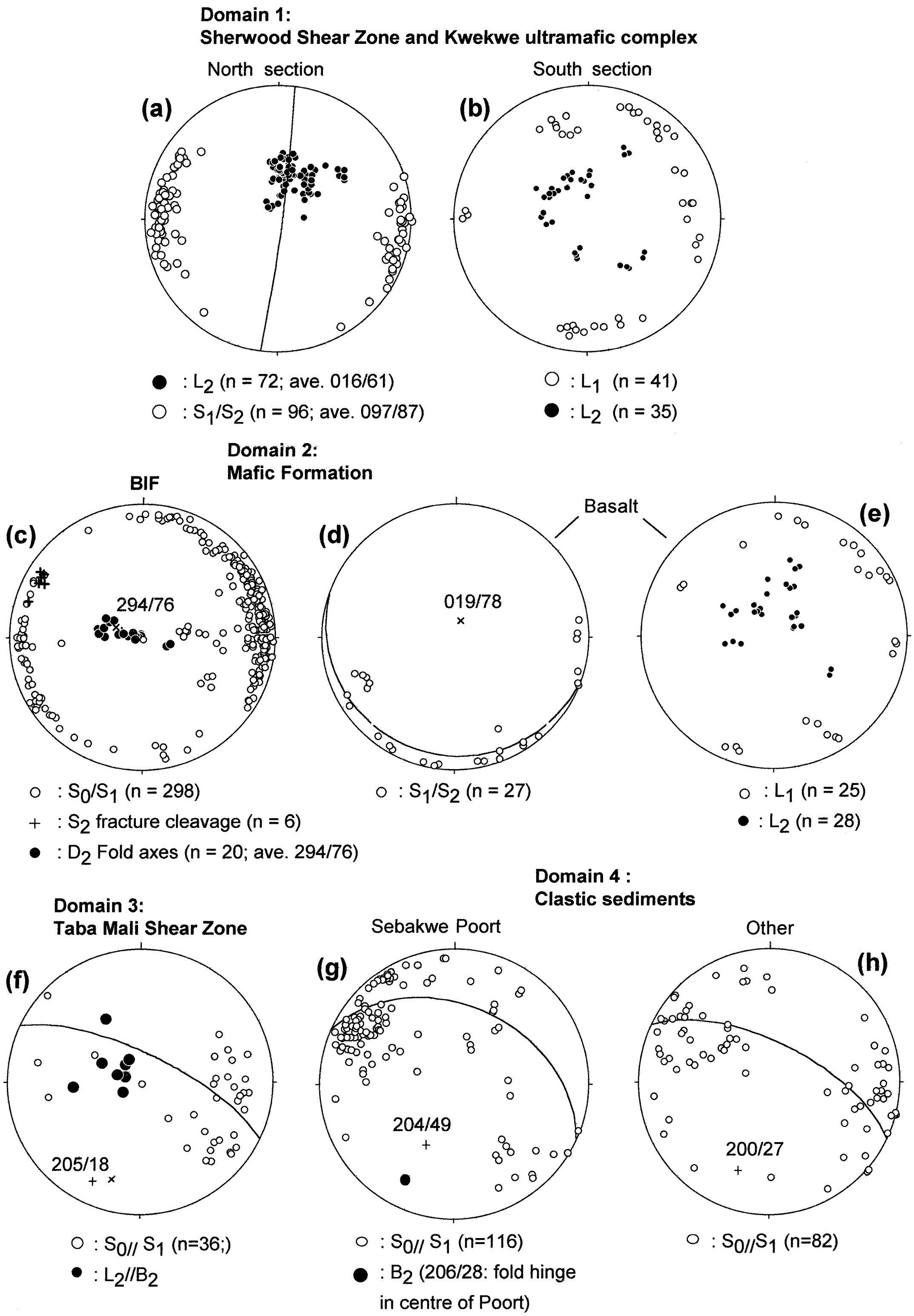

Fig. 7. Lower hemisphere equal area stereographic projections for poles to foliation and to the linear fabrics in the Sebakwe Poort area (see text for discussion).

D_1–D_2 features are truncated by several generations of slickensided brittle–ductile fracture zones and associated laminated quartz veins. An early set of fractures parallels S_2, and contains shallowly N-plunging slickenfibres resulting from dextral shear, possibly in response to ENE compression (Fig. 4a and b). The fractures were truncated by NW-trending feldspar porphyry dykes, N-trending dolerite dykes and a network of brittle–ductile shears described in Domain 2 (Fig. 4c).

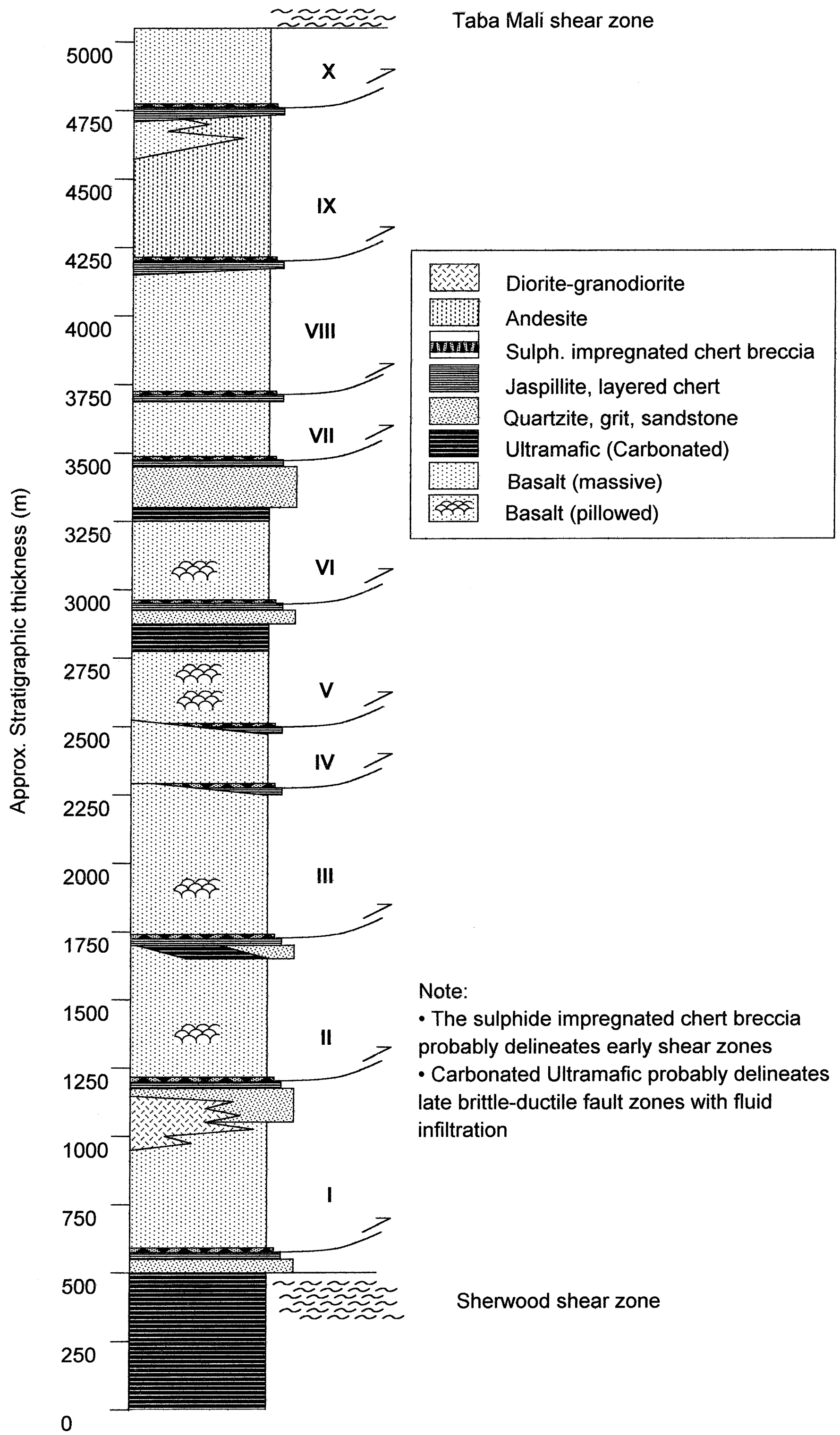

Fig. 8. Stratigraphy of the Mafic Formation south of Sebakwe River, comprising a ten-fold tectonic repetition of a similar lithological package.

5.2. Domain 2, complexly interleaved greenstones assigned to the Mafic Formation

The predominantly mafic volcanic rocks of Domain 2 are bounded by the Taba–Mali shear zone to the west and the Sherwood shear zone to the east (Fig. 5). South of the Sebakwe River (Fig. 6), the rocks are near-vertical, trend in a N or NW direction and young consistently to the W or SW.

The stratigraphic pile in this domain is ~4500-m-thick and consists of a ten-fold, tectonic repetition of basalt overlain by quartz grit, laminated siltstone, jaspilitic chert, and intensely deformed chert breccia and ironstone (Fig. 8). The breccia consists of angular jaspilitic blocks embedded in a network of gossanous magnetic veins. Near its base the jaspilitic blocks fit like pieces in a jig-saw puzzle, but this coherency is lost towards the contact with the ironstone horizon, in which an anastomosing foliation envelops isoclinally folded quartz lenses. Talc–tremolite–carbonate schist occurs along jaspilite–grit or jaspilite–ironstone contacts. This ultramafic schist is strongly sheared and extensively carbonated and forms protrusions that can be traced into the Kwekwe Ultramafic Complex.

The 10 cyclic units (Fig. 8) south of the Sebakwe River represent 10 tectono–stratigraphic blocks, bound by D_1 shear zones that anastomose and merge to the NW. North of the river, other tectonic blocks can be recognised (Fig. 6), including komatiitic basalt blocks (Buchholz, 1995) and a sliver of 3565 Ma quartzo–feldspathic gneiss (Horstwood, 1998) with a sheared and partly carbonated talc schist along its eastern contact and a western contact masked by intrusive diorite.

Domain 2 rocks contain a layer-parallel S_1 foliation and shallowly plunging L_1 mineral lineation (Fig. 7c and d) that is weakly developed, except within D_1 shear zones. Unambiguous fabric asymmetries were not observed, but the sigmoidal shape of the regional shear zone pattern (Fig. 6) suggests an apparent dextral shear sense component.

Many S_1 foliation planes in basalt contain an L_2 lineation defined by oriented amphibole and chlorite crystals that overgrow amphibole grains aligned in L_1. L_2, plunges steeply N, and parallels the axes of open to closed folds, best preserved in chert and ironstone horizons (Fig. 7c and e). It also parallels the π-pole (Fig. 7b) defined by the large-scale variations in trend of S_0/S_1 planes. A near vertical NE-trending fracture cleavage is locally preserved along the axial planes of D_2 folds in chert units.

D_1–D_2 features were overprinted by several sets of auriferous, brittle–ductile shears (Buchholz, 1995; Mackegeney, 1995). Early, N-trending shears have been described with Domain 1. These are truncated by NE-dipping porphyry dykes and a network of slickensided faults, that are consistent with formation in a N–S compressional field with vertical extension (Fig. 4c).

5.3. Domain 3, the Taba–Mali shear zone

The boundary zone between Domains 2 and 4 is the 50–100-m-wide Taba–Mali shear zone (Fig. 6; Campbell and Pitfield, 1994) characterised by intensely contorted and disrupted bedding planes within shale and siltstone horizons that are carbonated and ferrugenised. Primary bedding and foliation trends in both adjoining domains have been truncated.

The Taba–Mali shear zone dips steeply west, and consists of a composite $S_0/S_1/S_2$ schistose zone, with complexly contorted D_2 folds preserved in surfaces normal to steeply plunging fold axes. A steep L_2 mineral lineation parallels the fold axes causing a striped appearance in surfaces parallel to the fold axes. No unambiguous shear sense was observed, although anastomosing foliation traces in schist along the Sebakwe River appear to suggest an E-up, dextral sense of movement.

5.4. Domain 4, intensely folded clastic sediments assigned to the Shamvaian Group

Rocks in Domain 4 (Fig. 6) comprise clastic sediments with well-preserved sedimentary structures (Table 1). At Sebakwe Poort structural relationships are well illustrated in a 400-m-thick conglomerate unit that grades from underlying cross-bedded sandstone and shows an overall coarsening upward trend reflecting increased basin margin activity during deposition. The outcrop pattern of the conglomerate is determined by a kilometre-scale, NE-plunging synclinal D_2 synform, which to the NE is truncated by the Taba–Mali shear zone (Figs. 6 and 9). A 100-m-scale anticlinal D_1 antiform, well-exposed in the river bed at the gorge, is folded in the core of the D_2 synform (Fig. 9a).

The upper contact of the conglomerate unit with overlying siltstone consists of a <0.1-m-wide D_1 shear zone that locally truncates the conglomerate beds at a low angle. At outcrops in the main gorge, splays of this shear zone are exposed as steep, ESE-dipping, 5–15-cm-wide ultramylonite horizons with steeply S-plunging lineations and S–C fabrics consistent with reverse-sinistral movement (Fig. 9a). Quartz–sulphide veins are associated with the shears. The main D_1 shear zone can be traced around the D_2 synform into its SE limb, where layering in conglomerate is folded inwards along 50-m-scale, moderately E-plunging, chevron folds (Figs. 6 and 9) with quartz veining along their axial planes. The D_1 shear zone truncates S_0 as it kinks inward, and the structures are interpreted as fault-bend folds. Further NE the D_1 shear zone cuts the conglomerate horizon and continues into surrounding shale, where it is well-exposed in the Sebakwe River as a 10-m-wide zone of strongly contorted layering (Fig. 9a). In this zone S_0 has been broken in a series of lozenge-shaped packages, enveloped by ultramylonite horizons or truncation surfaces that are only a few centimetres wide. Mineral lineations have not been observed on the fine-grained shear surfaces, but the shape of the low-strain lozenges indicates a sinistral shear component (Fig. 9a).

At Sebakwe Poort the original D_1 features in both limbs of the D_2 synform can be reconstructed, by rotating the limbs of the D_2 synform back to the horizontal (Fig. 9b). D_1 fold axes in both limbs rotate back to near-horizontal, NNW-trending orientations, with the central anticline becoming a W-verging, recumbent fold. The D_1 mylonite zone at the top of the conglomerate rotates back to horizontal with a WNW-trending lineation indicative of E over W movement (Fig. 9c). Thus, D_1 structures in the conglomerate

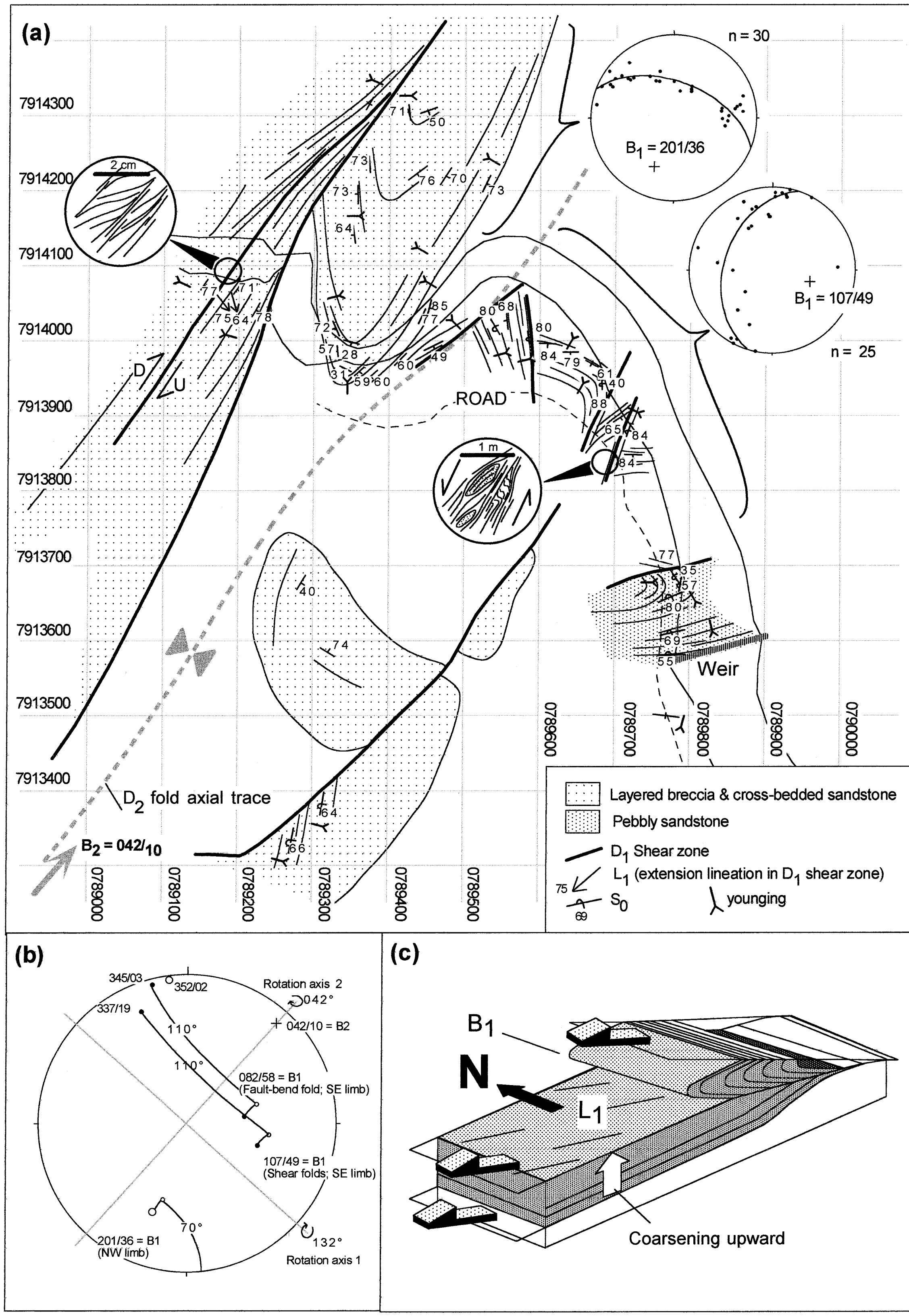

Fig. 9. (a) Geology at Sebakwe Poort, showing D_1 deformation geometries (recumbent fold, fault-bend chevron folds, and thrust zone) that have been folded around a D_2 upright synform. The map is projected in UTM, Arc 1950 (Zimbabwe). (b) By rotating the limbs of the D_2 synform back to horizontal positions, the original D_1 geometrical relationships in both limbs of the D_1 synform have been reconstructed (c).

are consistent with a footwall ramp along a thrust plane, with chevron folds in the conglomerates representing fault-bend folds (Boyer and Elliott, 1982; Butler, 1982), and the anticline representing a recumbent fold structure in the hanging wall; all indicative of top-to-the-W movement. It is possible that development of the thrust coincided with deposition of the highly angular conglomerate fragments and that the coarsening upward cycle marks the advance of the thrust front.

The amount of displacement on the D_1 mylonite zone cannot be accurately assessed, but minimum displacements *must* have been in the order of several kilometres, to allow for the complete truncation and dismemberment of the coarse-grained, 400-m thick conglomerate horizon. Considering that the mylonite horizon is less than 0.2 m wide, the extreme localisation of strain and correspondingly high local strain rates imply significant strain weakening mechanisms were operating within the zone.

D_1 mylonite zones and associated isoclinal intrafolial folds are common throughout the sedimentary succession in Domain 4. They are narrow wherever they are exposed, and can be traced as discrete truncation surfaces over long distances outlining duplex geometries that disrupt primary stratigraphy (Fig. 6). D_1 is associated with a layer-parallel slaty cleavage in fine-grained micaceous horizons. This S_1 cleavage is locally folded around D_1 folds, and is, therefore, assumed to have developed as part of a progressive thrusting and recumbent folding event.

Throughout Domain 4, the composite S_0/S_1 foliation is folded around mostly WNW-verging (Harrison, 1970; Campbell and Pitfield, 1994) and SSE-plunging D_2 folds (Fig. 7g and h). Such folds are associated with an axial planar slaty cleavage in fine-grained horizons, and a disjunctive cleavage in sandstone. D_2 folds are locally refolded by 50–100-m-scale, open recumbent folds (D_3) that are associated with a flat lying spaced fracture cleavage. D_3 fold axes are near horizontal and trend NNE.

6. Discussion

6.1. Summary of the deformation history of the Kadoma–Kwekwe area

Domains in the MGB have unique deformation histories, and structural correlations cannot be made, unless much detail is provided. Large shear zones separate domains, and transect a variety of older features preserved inside domains. Table 2 shows a summary of events recognised within the domains, and an attempt to correlate the events on the basis of shared features such as mineral lineation, kinematics and metamorphic grade. On the basis of this correlation, five regional deformation events can be defined, termed *DI* to *DV*.

Several early foliations and intrusive events are exclusively preserved in the Rhodesdale GGC and grouped as *DI*. Since this terrane is older than most of the surrounding greenstones (ca. 3.5 Ga as opposed to 2.9–2.7 Ga; Wilson et al., 1995; Horstwood, 1998), it is likely that many *DI* features predate formation of the greenstones. This paper is mainly concerned with the deformation of the MGB, and *DI* features will not be further considered. The Rhodesdale GGC is best interpreted as an old basement terrane or proto–cratonic block (Horstwood et al., 1999).

In the greenstone lithologies the earliest deformation features relate to layer-parallel slip, thin-skinned thrusting, recumbent folding, and clastic sedimentation, collectively called *DII*. In the Munyati shear zone, *DII* fabrics were not recognised. In the Sherwood shear zone, *DII* may be manifest by pre-*DIII* foliation planes and an earlier tremolite lineation that is locally preserved and folded around later lineations (Fig. 7b). In the Mafic Formation along the Sebakwe River, *DII* caused stacking and tectonic thickening of an original stratigraphy of basalt flows overlain by clastic sediment, tuff and jaspilite. Segments of older gneiss and felsic volcanic units (Horstwood, 1998) were caught up in this tectonic stacking. The *DII* shear zones are typically narrow ironstone horizons and breccias, and recumbent folding is absent. In contrast, *DII* events in the Felsic Formation west of Munyati, resulted in large-scale recumbent folding and younging reversals and a more penetrative layer-parallel foliation, suggesting somewhat higher-grade conditions during *DII*.

In the clastic sedimentary sequences along the Sebakwe and Munyati Rivers (Figs. 4 and 9a) *DII* is associated with recumbent folding and layer-parallel to low-angle shearing along narrow (<0.2 m) mylonite horizons that accommodated kilometres of displacement (to explain the dismemberment of the conglomerate unit at Sebakwe Poort). Removing later deformation effects (Fig. 9) suggests that *DII* resulted from WNW-directed thrusting and recumbent folding. The major coarsening upward cycle within angular conglomerate, which underlies the dominant thrust plane in Sebakwe Poort, can be interpreted as syn-tectonic basin fill, i.e. the clastic sequences may have formed on large alluvial fan systems in front of westward moving thrust fronts. This may also explain the presence of deformed jaspilite clasts and numerous intraformational clasts in conglomerate around Munyati. If so, *DII* deformation would have occurred at extremely low metamorphic grades.

None of the conglomerate units near Sebakwe Poort or Munyati contain mafic or intermediate volcanic clasts (Table 1), in spite of the fact that basalt and intermediate volcanics surround these units. This strongly suggests that the source areas for the conglomerate were distant from the greenstone domains that currently flank the conglomerate units. This, as well as the variable metamorphic grade at which *DII* features in different domains appear to have formed, suggests that juxtaposition of at least some of the domains occurred later.

DIII features are similar in all domains and resulted in the formation of regionally penetrative fabrics (Table 2) characterised by a steep NE- to N-plunging lineation on a steep N- to NE-trending foliation. In shear zones this foliation is mylonitic, and in lower strain domains it forms an axial planar fabric to reclined upright folds (Table 2), with minor mylonite zones along attenuated limbs (*DIIIb*, Table 2). In all domains where kinematics on *DIII* shear zones could be determined, the shear sense is E-up, commonly with a dextral component of movement. In many places, the mineral lineation parallels the fold axis of reclined folds. Only within the Rhodesdale GGC does this event not represent the dominant fabric. Instead, *DIII* strain was partitioned along garnet–hornblende bearing mylonite zones that parallel the margin of the terrane, and that record the same E-up sense of shear. Apart from these amphibolite facies shear zones, all other fabrics related to *DIII* are defined by greenschist facies assemblages, and no obvious metamorphic breaks mark domain boundaries. This and the similarity of all *DIII* features indicate that juxtaposition of domains occurred then.

After *DIII*, the Sherwood shear zone accommodated *DIV* dextral shear across brittle–ductile fracture zones that approximately parallel the older ductile fabrics. Deformation may have resulted from ENE compression, similar to *DIII* (Fig. 4), and *DIV* events may represent the waning stages of *DIII* ductile deformation. The emplacement of N-trending, mafic dykes and NW-trending felsite bodies followed *DIV*.

DV events were associated with slickensided fractures with mostly horizontal striations. Extensive silicification (e.g. quartz veining), carbonatisation and gold mineralisation accompanied shearing. The Munyati shear zone accommodated sinistral slip during *DV*, whereas a network of shears with widely varying orientations and kinematics developed in other domains. All *DV* fault planes are consistent with N–S compression and a principal extension direction that is either vertical or E–W horizontal (Fig. 4), indicating near uniaxial stress conditions.

The intrusive Kwekwe Ultramafic Complex takes a special position in the accretionary history. Its relative age can be ascertained from its intrusive relationship with the Rhodesdale GGC to the east and the tectonic pile of Mafic Formation rocks to the west. At Sebakwe Poort protrusions of ultramafic rocks emplaced along *DII* thrust planes are strongly deformed, but continuous with the main Kwekwe Ultramafic Complex whilst the underlying greenstone stratigraphy is duplicated. This suggests that emplacement post-dated *DII* stacking of the Mafic Formation. The dominant fabric in the ultramafics can be unambiguously linked to the *DIII*, east-up thrusting events. Therefore, the Kwekwe Ultramafic Complex was probably emplaced between late-syn *DII* and early syn-*DIII* times. This suggests that the *DII–DIII* shortening and crustal thickening events were contemporaneous with the emplacement of large, sheet-like ultramafic intrusions (c.f. Dirks and Jelsma, 1998; Jelsma and Dirks, 2000a,b).

6.2. A tectonic scenario for the Midlands greenstone belt

The oldest event shared by all domains is *DIII* (Table 2), which occurred in response to E–W compression under mostly greenschist facies conditions. It resulted in W-directed thrusting on large shear zones such as the Munyati, Sherwood and Taba–Mali shears that juxtaposed the different structural–lithological blocks of widely varying age (Wilson et al., 1995; Horstwood, 1998). We, therefore, interpret this event as a major accretionary event, and each domain as a separate unit or thrust slice emplaced from a distant source. The accretion probably resulted in crustal thickening and may have been associated with a tectonic setting that involved low angle subduction or underplating (Dirks and Jelsma, 2000; Jelsma and Dirks, 2000a,b). The Rhodesdale terrane with its earlier internal fabrics can be interpreted as an old cratonic fragment caught up in the accretionary events.

If viewed on a larger scale, numerous additional, shear zone-bounded structural domains can be recognised in the MGB that also formed part of the *DIII* thrust system. This includes the large domain west of the N-trending Lily shear zone comprising the volcanic sequences of the Maliyami Formation (Wilson et al., 1995), and numerous smaller segments of mafic and felsic volcanic rocks as well as clastic sediments north of Munyati town (Fig. 2).

West of the Sebakwe Poort, the Munyati shear zone is intruded by quartz porphyry bodies dated at 2677 ± 6 Ma (U–Pb, single zircon, TIMS; Horstwood, 1998) giving a minimum age for *DIII* in this area. A maximum age may be presented by volcanic breccia of the What Cheer Formation, dated at 2683 ± 8 Ma (Pb–Pb, single zircon, SHRIMP; Wilson et al., 1995). Since this unit was also folded during *DII*, this age presents a maximum age for *DII* as well.

DII events resulted in recumbent folding, low-angle stacking and crustal thickening reminiscent of thin-skinned tectonic processes in more recent orogenic zones. These events probably occurred when most domains were separate and responding independently to tectonic shortening. Judging from the kinematics obtained for *DII* events (Fig. 9), *DII* and *DIII* can be interpreted as progressive events during E–W shorting. In this scenario, *DII* thickening of individual domains, was followed by juxtaposition of the domains and folding of their internal structures as they collided and were stacked across major, steeply E-dipping thrusts.

DII–DIII thrusting and crustal thickening coincided with the emplacement of the Kwekwe Ultramafic Complex along major *DIII* thrust planes, which probably occurred after 2683 Ma but before 2677 Ma. The reasons for concomitant lateral crustal thickening across shear zones and emplacement of primitive, mantle-derived ultramafic melts are unclear, but the relationship suggests crustal shortening occurred above thermally active mantle.

Following thrust stacking, crustal thickening and cooling, strain was partitioned along brittle–ductile, strike-slip zones. *DIV* dextral shear in the Sherwood shear zone suggests that strike-slip initially occurred in response to an E–W compressional field similar to the far field stress driving *DII–DIII* shortening. A subsequent shift in the main compressional direction to N–S could be linked to the Limpopo events (Treloar and Blenkinsop, 1995). Alternatively, it could be interpreted as an E–W extensional event resulting from extensional relaxation following E–W accretion and crustal thickening, similar to extensional collapse affecting modern day orogens. This interpretation fits the emplacement of N-trending dolerite dykes and other intrusive units and is preferred by us.

7. Conclusions

The observations made in the Kadoma–Kwekwe area can be summarised as follows:

1. The MGB consists of a series of shear zone-bounded domains with unique lithological and structural–metamorphic characteristics.
2. The domains, including old gneissic basement units, clastic sedimentary sequences and mafic and intermediate to felsic volcanic units were welded together across a network of steep, W-directed thrusts including the Munyati, Sherwood and Taba–Mali shear zones. Concomitant upright folding and 'minor' shear accommodated strain internal to the domains. These events occurred around 2680 Ma.
3. Prior to juxtaposition by thrusts, most domains experienced early thin skin-thrusting, recumbent folding and crustal thickening. In Sebakwe Poort it was possible to reconstruct the thickening to have occurred as a result of low angle WNW-directed thrusting with at least several kilometres of displacements across centimetre-wide shear planes. These events occurred around 2680 Ma.
4. The clastic sedimentary sequences show coarsening upward cycles below major thrust horizons and numerous interformational clasts, suggesting a genetic link between sedimentation and early thin-skinned thrust tectonics, i.e. the sequences may have partly developed as fan systems in front of advancing thrust sheets.
5. The Kwekwe Ultramafic Complex was probably emplaced as a large intrusive sheet along major shear zones contemporaneous with tectonic stacking around 2680 Ma.
6. Deformation post-dating ductile thickening includes several stages of brittle–ductile shear along reactivated thrust planes as well as networks of newly formed shear zones. This involved dextral shear along the Sherwood shear zone followed by sinistral shear along the Munyati shear zone. The two shear zones did not act as conjugate sets and accommodated strain separately as the principal compressive stress direction, σ_1, shifted from E–W to N–S.

There are several fundamental implications that result from these conclusions:

1. Because this part of the MGB consists of numerous shear zone-bounded domains with unique lithological characteristics, it is not possible to devise a regional stratigraphy. A simple stratigraphic concept based on a 'layer cake' stratigraphy is impossible to apply in spite of numerous past attempts (Macgregor, 1932; Harrison, 1970; Robertson, 1976; Stowe, 1980; Campbell and Pitfield, 1994; Horstwood, 1998). Instead, stratigraphic sequences should be defined for each shear zone-bounded block. Concurrent origins may be proven between stratigraphies if sufficient geochronological data is available. Simple lithostratigraphic correlations are unacceptable since it can be shown that current spatial relationships originated as a result of tectonic juxtaposition across shear zones that not only severely disrupted stratigraphy, but that also may have accommodated many kilometres of displacement. Tectonic juxtaposition and non-applicability of basic lithostratigraphic principles explains the incompatibility of certain age data, e.g. the contrasting ages obtained for the What Cheer and Mafic Formations (e.g. 2683 Ma (Wilson et al., 1995); 2880 Ma (Horstwood, 1998)). Similar conclusions have been drawn for other greenstone belts (Jelsma and Dirks, 2000a), and can probably be applied across the craton, casting doubt on the validity of existing stratigraphic correlations.
2. Related to the above argument, ultramafic sequences such as the Kwekwe Ultramafic Complex should not be simply treated as part of a constant stratigraphic sequence. Wilson (1979), for example, assigns the ultramafic intrusions to the Mashaba Ultramafic Suite and regards the intrusions as feeder remnants of (ultra)mafic volcanic flows. The structural observations presented here suggest that the emplacement of the ultramafic intrusions was controlled by the position of major thrusts such as the Sherwood shear zone. Implicit to this argument is the fact that many similar ultramafic sheets in adjacent greenstone belts may have been tectonically emplaced during large-scale thrusting processes and cannot be used for stratigraphic correlations.
3. Some workers have suggested that the clastic sedimentary sequences restricted to shear zone-bounded blocks were deposited in pull-apart basins formed in response to strike-slip along the bounding shear zones (e.g. Stowe, 1980; Campbell and Pitfield, 1994). This inference is flawed in that these interpretations ignore the early history of the shear zones. In addition, the bounding shears cannot be linked to facies distribution patterns in the sedimentary sequences, but cut primary layering. This, the presence of early structures and a conspicuous absence of mafic greenstone clasts in the conglomerates, make a late pull-apart origin for the sediments impossible (Harrison, 1970; Robertson, 1976). Instead they

represent packages of clastic sediments, caught up in the thrusting process.

4. Strike-slip motion on the main shear zones in the Midlands greenstone belt only occurred late in the tectonic history. There is no evidence that strike-slip movement resulted in large displacements, and it is wrong to attribute large-scale duplex-like geometries to strike-slip events (e.g. Stowe, 1980; Campbell and Pitfield, 1994). Instead, such geometries originated under ductile conditions during thrust-related events.
5. Detailed kinematic analysis of the Sherwood and Munyati shear zones demonstrates that these two shear zones are not a simple conjugate set as is generally assumed (e.g. Stowe, 1980; Campbell and Pitfield, 1994). The same probably applies to other major shear zones in the belt such as the Kadoma and Lily shear zones (Fig. 1). Each of these shears originated as major thrusts along domainal boundaries, and responded independently to subsequent cooling and shifts of the far field stress.

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